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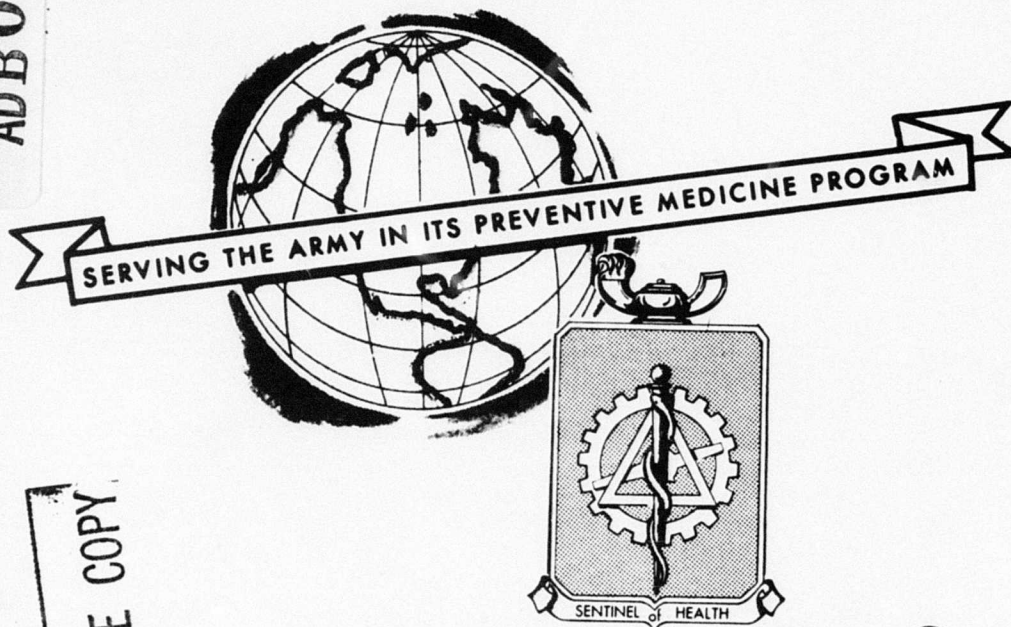
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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-080-76  
REFLECTIONS FROM ICE DURING LASER OPERATIONS  
US ARMY ARCTIC TEST CENTER  
FORT GREELY, ALASKA  
MARCH 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A special study was performed to study the effects of laser reflections from glazed ice and snow on the proposed laser ranges at Fort Greely. A representative of this Agency made measurements on glazed ice and snow during March 1976 on the proposed laser ranges.  The Arctic snow produced a diffuse reflection; however, the Arctic ice produced a laser reflection which was partly specular and partly diffuse.		



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DEPARTMENT OF THE ARMY  
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY  
ABERDEEN PROVING GROUND, MARYLAND 21010

12 MAY 1976

NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-080-76  
REFLECTIONS FROM ICE DURING LASER OPERATIONS  
US ARMY ARCTIC TEST CENTER  
FORT GREELY, ALASKA  
MARCH 1976

ABSTRACT

A special study was performed to study the effects of laser reflections from glazed ice and snow on the proposed laser ranges at Fort Greely. A representative of this Agency made measurements on glazed ice and snow during March 1976 on the proposed laser ranges.

The Arctic snow produced a diffuse reflection; however, the Arctic ice produced a laser reflection which was partly specular and partly diffuse.

It was concluded that the laser systems intended for Arctic tests may be operated safely on the proposed laser ranges if the operators are informed of the hazards and take the appropriate precautions.

It was recommended that a Laser Range Safety Officer be designated, that laser operations not be performed when the laser ranges are covered with melting snow or ice, and that baffles or a plastic attenuator be placed over the vehicle view blocks. It was further recommended that personnel not approach within 100 m of the laser target due to possible reflections from glazed ice.

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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-080-76  
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1. AUTHORITY.

- a. Letter, STEAC-OP-MI, US Army Arctic Test Center, 23 January 1976, subject: Arctic Environmental Laser Hazard Study, and indorsements thereto.
- b. Letter, HSE-AT/WP, this Agency, 9 December 1975, subject: Revised Mission Services, Third Quarter, FY76.

2. REFERENCES.

- a. Paragraph 2-35a(7), AR 10-5, Organization and Functions, Department of the Army, 1 April 1975.
- b. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.
- c. TB MED 279, Control of Hazards to Health from Laser Radiation, 30 May 1975.

3. PURPOSE. To evaluate potential health hazards associated with the use of the Ground Laser Locator Designator (GLLD), the AN/GVS-5 Hand-Held Laser Rangefinder, and the ABN Laser Tracker in an Arctic environment at Fort Greely, Alaska, and to make recommendations to eliminate exposure of personnel to potentially hazardous optical radiation from these devices.

4. GENERAL.

a. Background. The US Army Arctic Test Center, Fort Greely, Alaska, plans to test the GLLD, the AN/GVS-5, and the ABN Laser Tracker for operation under Arctic conditions. No laser ranges were presently available at Fort Greely. The US Army Arctic Test Center was concerned with possible hazardous laser reflections from ice and snow. A representative of the US Army Environmental Hygiene Agency made measurements of reflections from Arctic ice and snow and evaluated the proposed laser ranges during 10-11 March 1976.

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b. Instrumentation.

- (1) Spectra Physics, Model 134, 3 mW Helium-Neon Laser.
- (2) United Detector Technology Optometer, Model 40X.
- (3) EG&G, Model 580, Radiometer.

c. Abbreviations. A table of common technical terms (and units) along with other appropriate abbreviations is available in Appendix A. All abbreviations and units utilized in this report are included therein.

5. FINDINGS.

a. Laser Reflections.

(1) Snow. Reflections from snow indicated that snow was a nearly perfect diffuser. Since the lasers used in the planned test are not a diffuse reflection hazard, no hazard will result from reflections of the laser beam incident upon snow.

(2) Ice. Reflections from highly specular naturally occurring ice surfaces indicated a strong specular component in the reflection. At close distances, patterns as shown in Figure 1 were observed. Narrow bright areas were superimposed over a diffuse reflection. No truly collimated reflections were observed from ice.

(3) Water-Covered Ice. Reflections from ice covered with a thin layer of water resembled reflections from water alone. These reflections are hazardous since the laser beam retains its collimation. Reflections at near-grazing angles provide the most reflection and hence the greatest hazard. This effect is illustrated in Figure 2.

(4) Glass View Blocks. Reflections from glass view blocks produce a well-collimated beam, such as reflection from water; however, the pattern of optical radiation is altered slightly due to reflections from both the front and rear surfaces. Figures 3 and 4 illustrate the radiation pattern obtained when a piece of glass is rotated on an axis normal to the plane of the page. Curves are drawn for two laser polarizations. The curve represents the distance from the reflecting surface at which the radiant exposure from the laser falls below the protection standard level.

b. Measurements of Ice Reflections. Measurements were taken on a naturally occurring slab of glossy ice on the bank of a frozen lake on Texas Range at Fort Greely. A 4 mW helium-neon laser was placed so the beam struck the ice surface at a near-grazing angle. The pattern on

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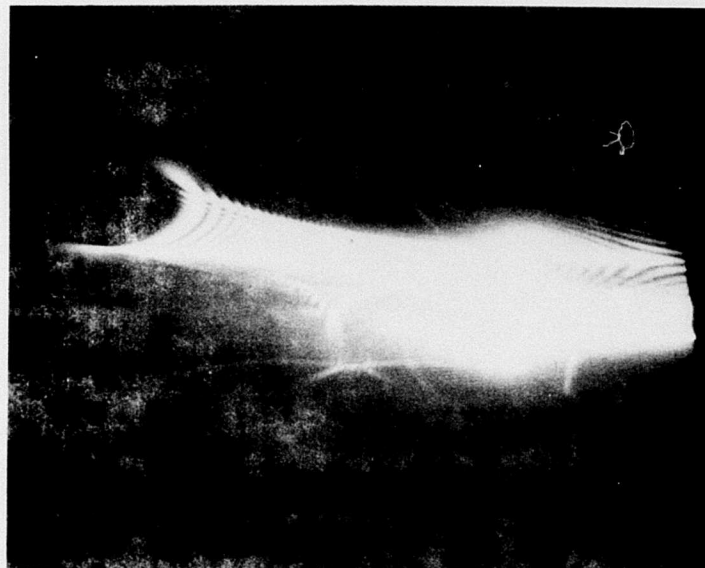
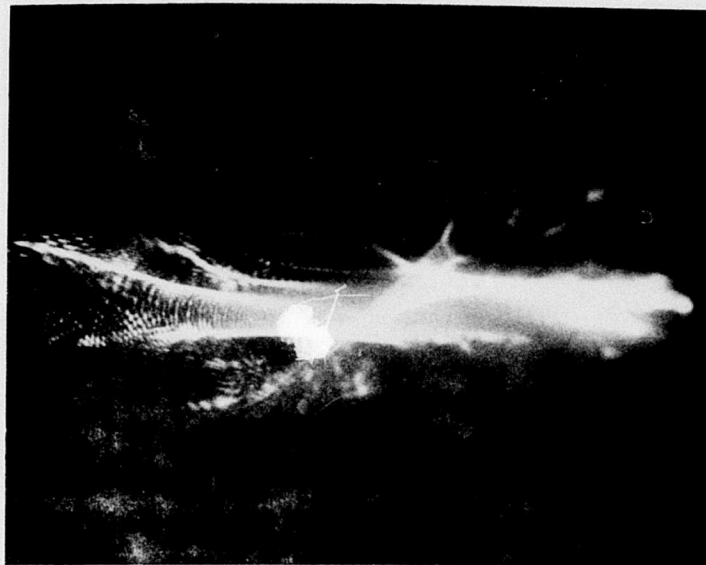


Figure 1. Samples of the Types of Laser Reflections Observed from Ice Imaged on a Card Placed 0.5 to 1.0 m from the Ice Surface.

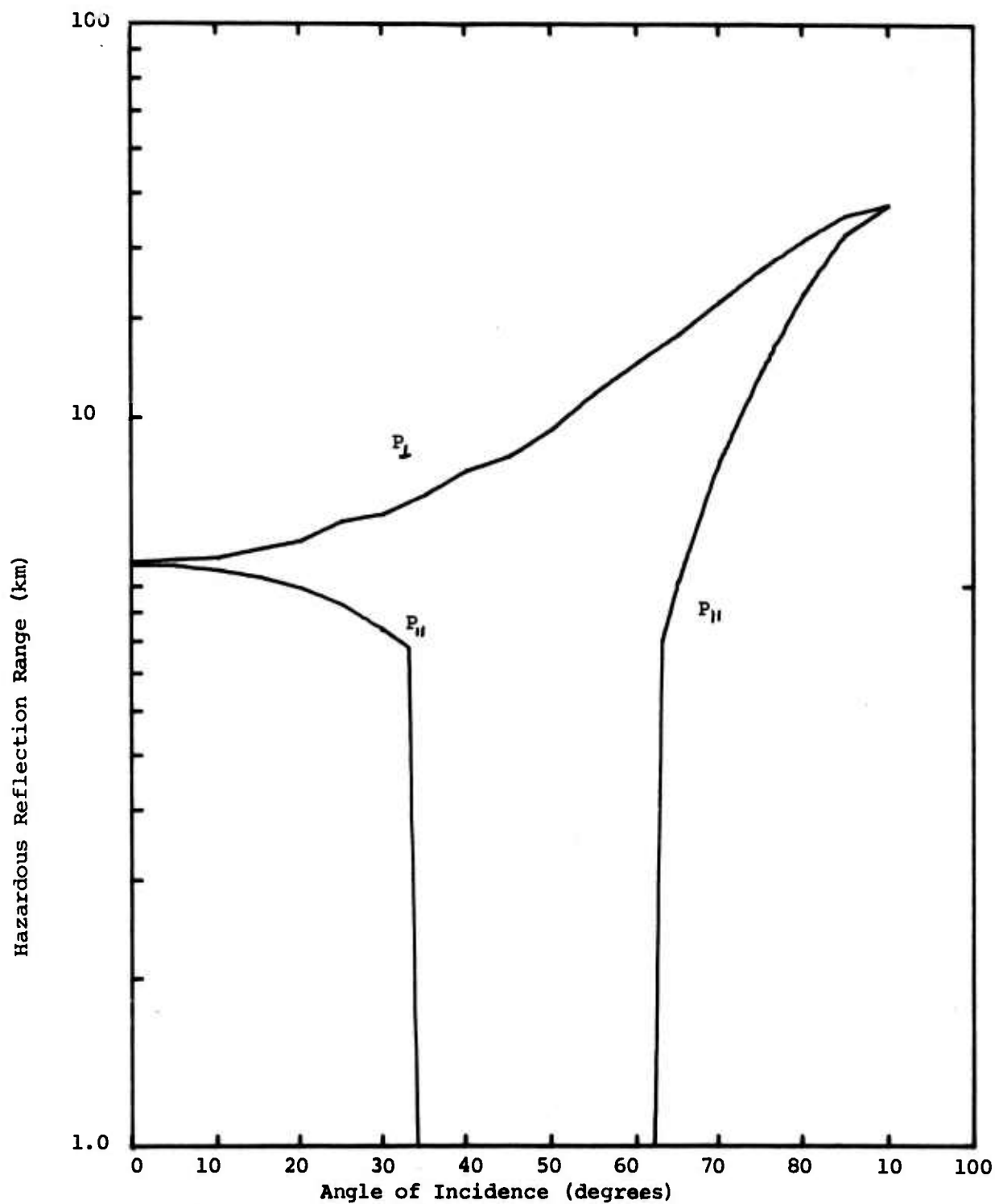


Figure 2. The Hazardous Distance of a Laser Reflection from Water-Covered Ice at Various Angles of Incidence. Curves are drawn for two laser polarizations.

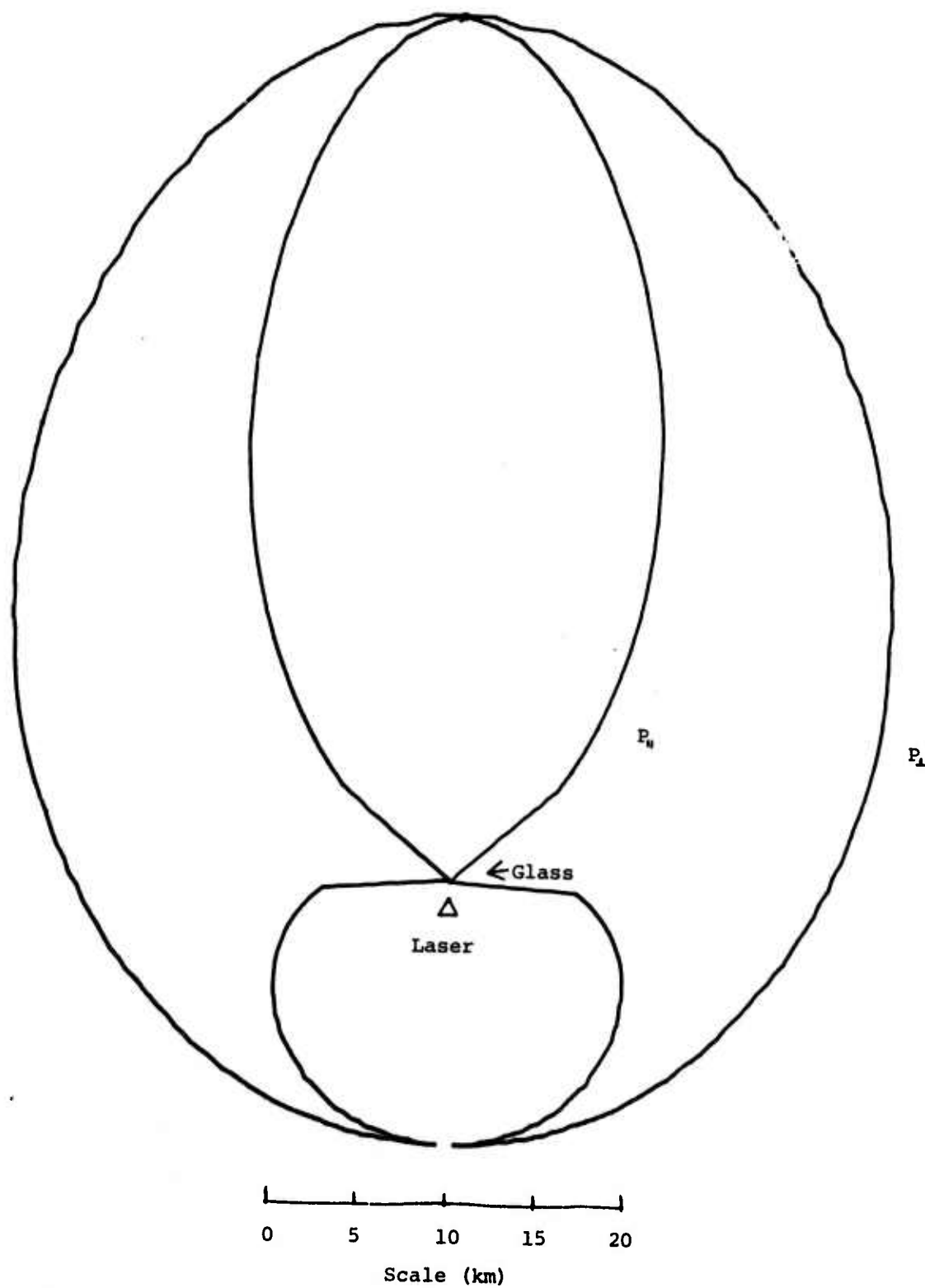


Figure 3. The Hazardous Area Created from the GLLD Laser Beam Striking on a Flat Glass Surface Located 1 km from the Laser. Curves are drawn for two laser polarizations.

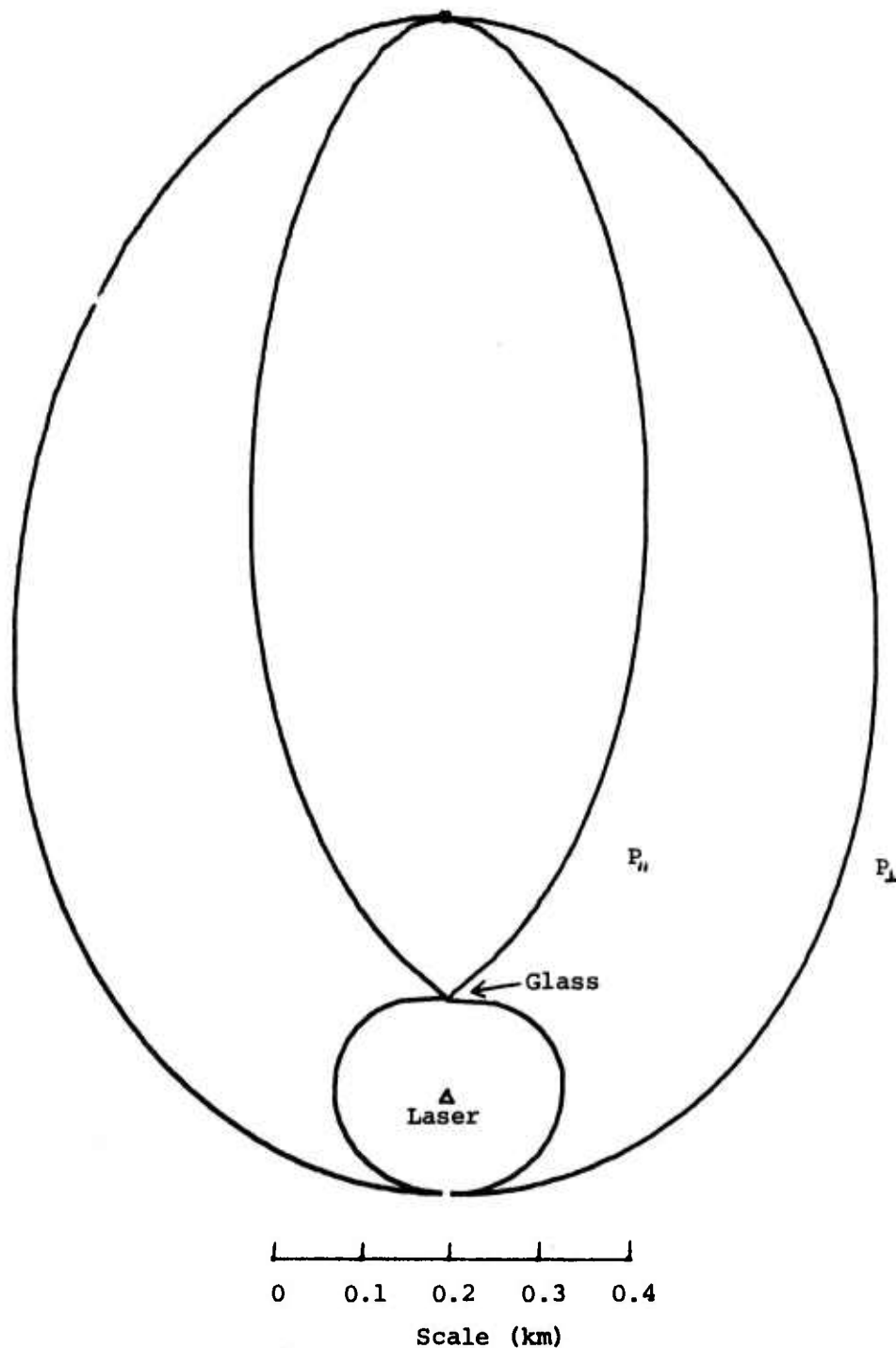


Figure 4. Hazardous Areas Created from the AN/GVS-5 Laser Striking a Flat Glass Surface Located 100 m from the Laser. Curves are drawn for two laser polarizations.

a white card from a reflection was an elongated oval. At 13 m from the ice, the size of the pattern was approximately 20 cm x 2.5 m. Measurements taken within the reflected beam are given in the Table below:

TABLE. REFLECTED BEAM MEASUREMENTS

<u>Distance</u>	<u>Glossy Ice</u>	<u>Normal Ice</u>
3 m	20 $\mu\text{W}/\text{cm}^2$	8 $\mu\text{W}/\text{cm}^2$
6 m	7 $\mu\text{W}/\text{cm}^2$	1.6 $\mu\text{W}/\text{cm}^2$
12 m	1 $\mu\text{W}/\text{cm}^2$	--

c. Irradiance Versus Range from Ice Reflections. The above measured values are plotted in Figure 5. The values for the GLLD and AN/GVS-5 are also plotted on the same figure assuming the same percentage of reflection. The protection standard is exceeded out to a distance of 100 m for the GLLD and 35 m for the AN/GVS-5. The effective divergence of the reflected beam was 45 mrad.

d. Laser Ranges. The proposed laser range was located on Texas Range. The GLLD laser and the AN/GVS-5 laser would be used at elevated firing points. The main target area is along Meadows Road. During the winter, this road is covered with packed snow and ice. The road parallels the Delta River with a sufficient buffer zone to prevent the laser beam from striking the river. A distant target area is located across the river in the Delta River Impact Area near the bank of the Delta River. Targets may be located in this area to provide a sufficient buffer zone to the water's edge. During lasing to this target area, the laser beam will maintain a height well above ground personnel. The general area around these two laser firing areas is tree covered and totally unpopulated. Distant mountains provide a final, although unnecessary, backstop. Airspace over the laser ranges is restricted.

## 6. DISCUSSION.

### a. General Hazard Analysis.

(1) The laser system, except for its inability to penetrate targets, can be treated like a direct-fire, line-of-sight weapon, such as a rifle or machinegun. Thus, the hazard control precautions taken with respect to those types of weapons will provide most aspects of the safe environment required for laser use. Special control measures for laser use are discussed below.

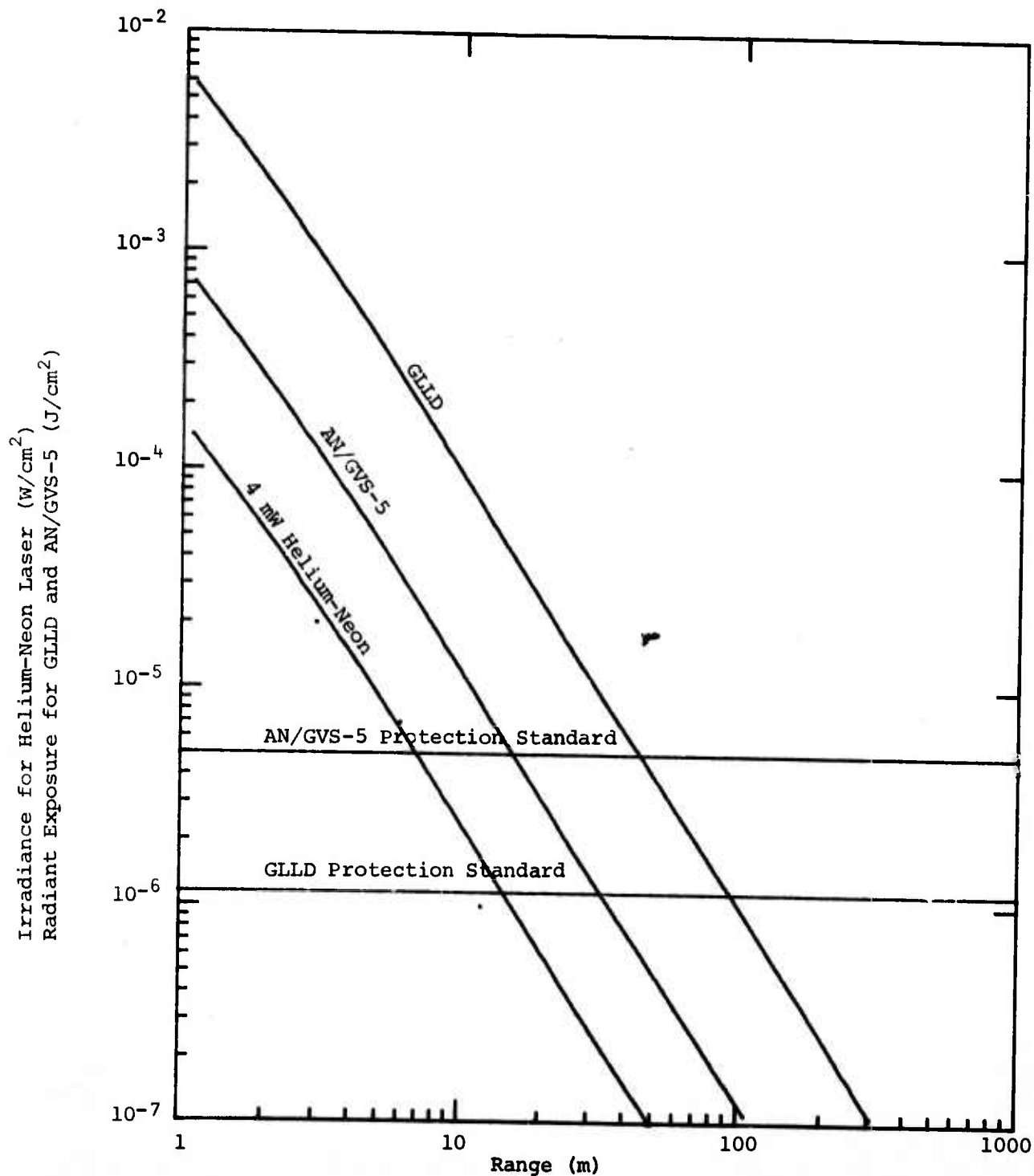


Figure 5. Reflected Laser Energy from Ice for a 4 mW Helium-Neon, the GLLD, and the AN/GVS-5. Measurements taken with the helium-neon laser indicate that the energy decreases as  $1/r^2$ .



(2) The hazard from these types of laser devices is limited to exposure to the unprotected eye of individuals within the direct laser beam or a laser beam reflected from specular (mirror-like) surfaces. In some cases, however, viewing a diffuse surface reflection at close range is also potentially hazardous. Serious eye damage with permanent impairment of vision can result to unprotected personnel exposed to the laser beam.

(3) Essentially, the laser beam travels in a straight line, so it is necessary to provide a natural backstop, such as a hill or the ground behind the target during laser firing. Calculated nominal hazardous ranges often extend beyond 35 km, and the use of optical viewing instruments within the beam could extend this hazardous range considerably. For this reason, and because of atmospheric effects upon the beam, *the designation of a single "hazardous range" for ground or airborne firing range safety purposes is not feasible for most testing and training purposes.* The nominal hazardous range may be used in determining the extent of restricted airspace if the beam could be directed or reflected into the air, since stabilized optical telescopic systems are not used in commercial and general aviation.

(4) Every object that the laser beam strikes will reflect some energy back toward the laser. In most cases, this energy is a diffuse reflection and is normally not hazardous; however, certain shiny reflecting surfaces must be avoided as targets to prevent a hazardous amount of radiation from being reflected. These conditions are described in succeeding paragraphs.

b. General Hazard Control Procedures. The necessary hazard control procedures for laser tests at Fort Greely are provided in Appendix B.

c. Laser Reflections. Laser reflections are usually divided into specular or diffuse reflections. Reflections from snow and other painted objects are primarily diffuse, whereas reflections from glass or polished metal are primarily specular. Reflections from ice are a combination of both a diffuse component and a specular component. The hazard from this type of reflection would depend on the retinal image shape and size. A worst-case evaluation would assume the retinal image to be a point source similar to viewing the laser beam directly. This assumption was used to determine the 100-m range for the GLLD ice reflections and the 35-m range for AN/GVS-5 hazardous ice reflections. These distances may be slightly conservative, but should be used until more data are available.

d. Hazard Distances. The protection standards for intrabeam viewing of a single 1064 nm pulse is  $5 \times 10^{-6} \text{ J/cm}^2$ . For viewing multiple pulses of 10 or 20 Hz, this standard is reduced by a factor of 0.32 or 0.28, respectively. The distance at which the GLLD emits a radiant exposure less than the single pulse protection standard is 23 km. For the multiple pulse protection standard this value is 46 km. If the

output beam is collected with 13X magnifying optics, this distance is 230 km. For the AN/GVS-5, these values are 1.1 km for unaided viewing or 13.3 km for optically aided viewing. These distances may be reduced to the laser-to-target distance when appropriate backstops are used.

e. Laser Protective Eyewear. Laser safety goggles may be used to protect personnel from the laser beam in the target area; however, goggles with curved lenses should be used to prevent collimated specular reflections from the goggle. If all specular reflections can be eliminated from the target area, laser protective goggles need not be worn by personnel not in the target area. Laser goggles with a minimum optical density at the laser wavelengths of 4.2 for unaided viewing or 5.7 for optically aided viewing will provide adequate protection for this proposed laser test.

7. CONCLUSION. The laser systems to be used at Fort Greely emit optical radiation levels exceeding current protection standards for the eye. However, these devices may be operated safely at the proposed test sites provided that the operators are informed of the potential hazards and take appropriate precautions.

8. RECOMMENDATIONS.

a. Select a Laser Range Safety Officer who will be responsible for the safety of all laser tests [para 5-38b(2), AR 40-5].

b. Avoid laser operation during periods of the year when the laser target area is covered with melting snow and ice if forward reflections of the beam can enter occupied areas (para 5-31, AR 40-5).

c. Either provide baffles which prevent the laser beam from striking the flat glass view blocks on target vehicles or cover the view blocks with a material which will eliminate specular reflections and also attenuate the transmitted laser beam with an optical density of 6 (para 5-31, AR 40-5).

d. Follow the guidelines provided in Appendix B for establishing ranges for ground located laser systems [para 1-5d(2), AR 40-46].

e. Do not allow unprotected personnel to approach within 100 m of the laser target area due to possible hazardous reflections from glazed ice (para 1-4d, AR 40-46).

Nonionizing Radn Prot Sp Study No. 42-080-76, Mar 76

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APPENDIX A  
USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS<sup>1, 2</sup>

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	$Q_e$		Joule (J)	Quantity of Light	$Q_v$	$Q_v = \int \phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	$W_e$	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter (J·m <sup>-3</sup> )	Luminous Energy Density	$W_v$	$W_v = \frac{dQ_v}{dV}$	talbot per square meter (lm·s·m <sup>-3</sup> )
Radiant Power (Radiant Flux)	$\phi_e, P$	$\phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	$\phi_v$	$\phi_v = 680 \int \frac{d\phi_e}{d\lambda} V(\lambda) d\lambda$	lumen (lm)
Radiant Exitance	$M_e$	$M_e = \frac{d\phi_e}{dA} = \int L_e \cos\theta \cdot d\Omega$	Watt per square meter (W·m <sup>-2</sup> )	Luminous Exitance	$M_v$	$M_v = \frac{d\phi_v}{dA} = \int L_v \cos\theta \cdot d\Omega$	lumen per square meter lm·m <sup>-2</sup>
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	$E_e$	$E_e = \frac{d\phi_e}{dA}$	Watt per square meter (W·m <sup>-2</sup> )	Illuminance (luminous flux density)	$E_v$	$E_v = \frac{d\phi_v}{dA}$	lumen per square meter (lm·m <sup>-2</sup> ) lux (lx)
Radiant Intensity	$I_e$	$I_e = \frac{d\phi_e}{d\Omega}$	Watt per steradian (W·sr <sup>-1</sup> )	Luminous Intensity (candlepower)	$I_v$	$I_v = \frac{d\phi_v}{d\Omega}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	$L_e$	$L_e = \frac{d^2\phi_e}{d\Omega \cdot dA \cdot \cos\theta}$	Watt per steradian and per square meter (W·sr <sup>-1</sup> ·m <sup>-2</sup> )	Luminance	$L_v$	$L_v = \frac{d^2\phi_v}{d\Omega \cdot dA \cdot \cos\theta}$	candela per square meter (cd·m <sup>-2</sup> )
Radiant Exposure (Dose, in Photobiology)	$H_e$	$H_e = \frac{dQ_e}{dA}$	Joule per square meter (J·m <sup>-2</sup> )	Light Exposure	$H_v$	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	$K$	$K = \frac{\phi_v}{\phi_e}$	lumen per watt (lm·W <sup>-1</sup> )
				Luminous Efficiency (of a broad band radiation)	$V(\cdot)$	$V(\cdot) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency <sup>3</sup> (of a source)	$\eta_e$	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy <sup>3</sup> (of a source)	$\eta_v$	$\eta_v = \frac{\phi_v}{P_i}$	lumen per watt (lm·W <sup>-1</sup> )
Optical Density <sup>4</sup>	$D_e$	$D_e = -\log_{10} \tau_e$	unitless	Optical Density <sup>4</sup>	$D_v$	$D_v = -\log_{10} \tau_v$	unitless
				Reinal Illuminance in Trolands	$F_t$	$F_t = \frac{L_v}{S_p}$	troland (td) = luminance in cd·m <sup>-2</sup> times pupil area in mm <sup>2</sup>

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript  $\lambda$ . For example, spectral irradiance  $H_\lambda$  has units of W·m<sup>-2</sup>·m<sup>-1</sup> or more often, W·cm<sup>-2</sup>·nm<sup>-1</sup>.

2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or  $\mu$ m are most commonly used to express wavelength.

3.  $P_i$  is electrical input power in watts. 4.  $\tau$  is the transmission

5. At the source  $I = \frac{dI}{dA \cos\theta}$  and at a receptor  $I = \frac{dI}{dA}$

## APPENDIX B

### ESTABLISHING RANGES FOR GROUND LOCATED LASER SYSTEMS

1. Scope. The guidance provided deals with range operations in which the laser rangefinder, designator or illuminator is ground located and has a hazardous range of at least 1 km. Because of the varied characteristics of laser systems in use, these guidelines should not be applied to laser systems other than those having a beam divergence of  $1^\circ$  (17 milliradians) or less.

2. Background.

a. The laser system except for its inability to penetrate targets can be treated like a direct-fire, line-of-sight weapon, such as a rifle or machine-gun. Thus, the hazard control precautions taken with respect to those types of weapons will provide most aspects of the safe environment required for laser use. Special control measures for laser use are discussed below.

b. The hazard from these types of laser devices is limited to exposure to the unprotected eye of individuals within the direct laser beam or a laser beam reflected from specular (mirror-like) surfaces. In some cases, however, viewing a diffuse surface reflection is also potentially hazardous. Serious eye damage with permanent impairment of vision can result to unprotected personnel exposed to the laser beam.

c. Essentially, the laser beam travels in a straight line, so it is necessary to provide a backstop, such as a hill behind the target during laser firing (see Figure 1). Calculated nominal hazardous ranges often extend even beyond 8 kilometers, and the use of optical viewing instruments within the beam could extend this hazardous range considerably. For this reason, and because of atmospheric effects upon the beam, the designation of a single "hazardous range" for ground firing range safety purposes is not feasible for most testing and training purposes. The nominal hazardous range may be used in determining the extent of restricted airspace if the beam could be directed or reflected into the air.

d. Every object that the laser beam strikes will reflect some energy back toward the laser. In most cases, this energy is a diffuse reflection and is normally not hazardous, however, certain shiny reflecting surfaces must be avoided as targets to prevent a hazardous amount of radiation from being reflected. These conditions are described in succeeding subparagraphs and illustrated in Figure 2.

3. Laser Range Safety Officer. A person familiar with the range control procedures required for laser operations is termed in this bulletin the "Laser Range Safety Officer" (LRSO). The LRSO is responsible for the following:

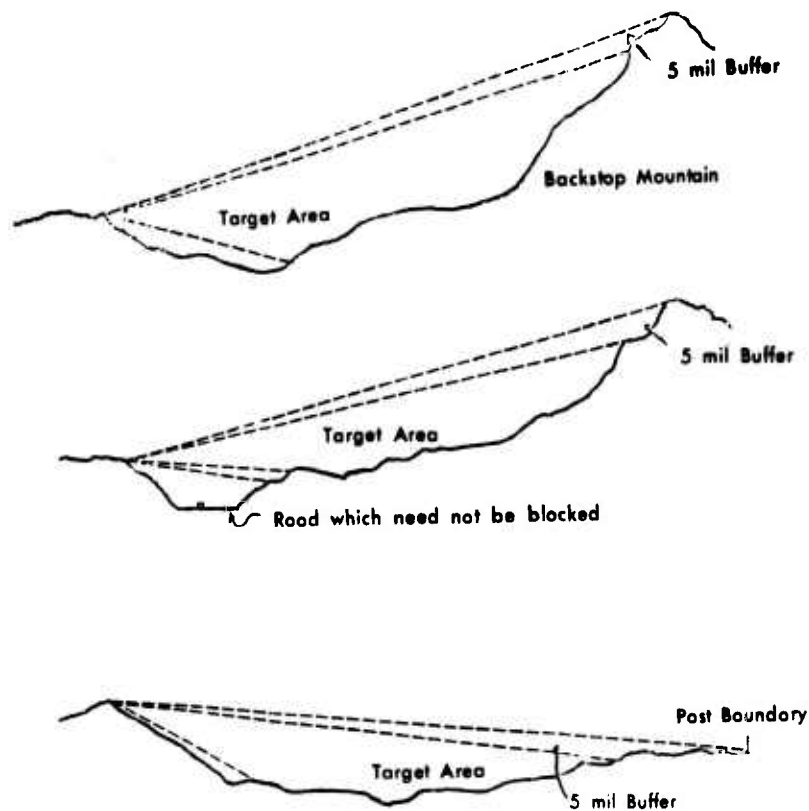


Figure 1. Example of the Use of a Backstop and Buffer Zones

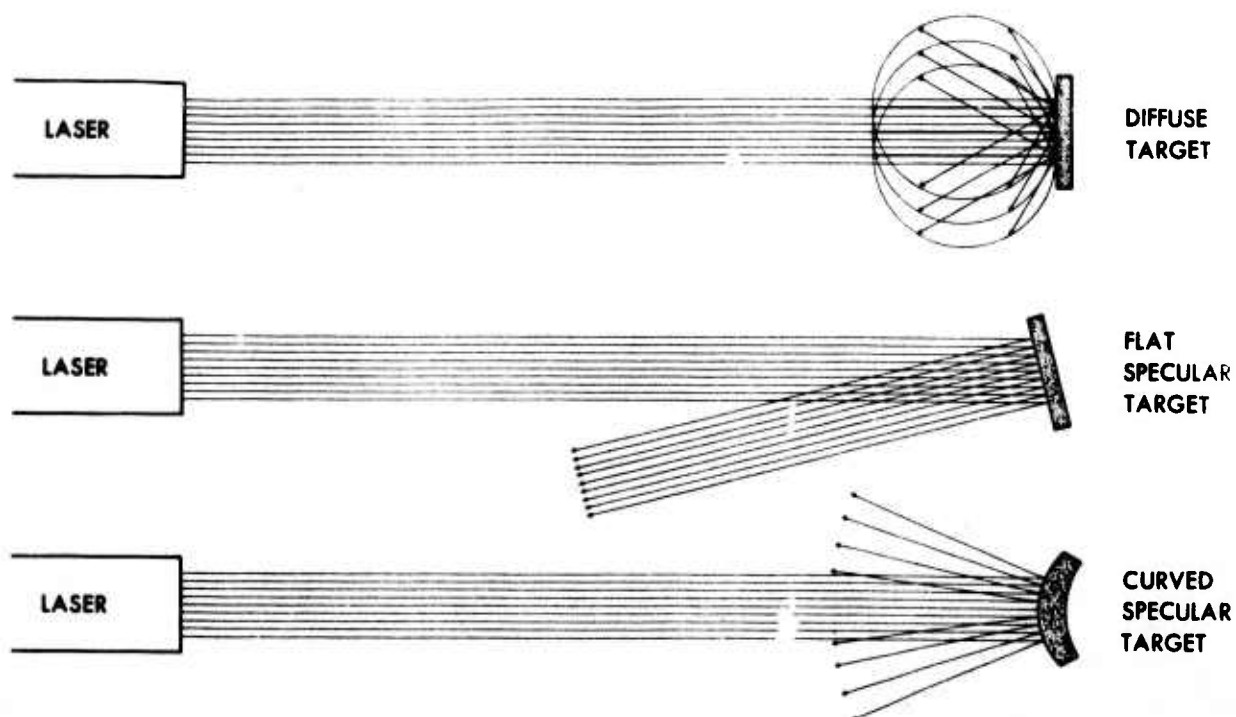


Figure 2. Reflection Patterns from Diffuse, Flat, Specular, and Curved Specular Surfaces



a. The LRSO will thoroughly instruct all personnel authorized to participate in the laser operation regarding safety precautions to be followed. This instruction should be of such scope as to alleviate any fears generated by a lack of knowledge that may be harbored by participating personnel.

b. The LRSO will insure that safe standing operating procedures are implemented and will establish target areas with the appropriate buffer zones (see paragraph 9) around the target area as defined by the greatest laser-to-target distance. The LRSO will provide adequate surveillance of the target area to insure that no unauthorized personnel enter that area. He will insure that communication with personnel in the target area is maintained to insure that protective eyewear is worn as required during operation. Any break in communication will automatically terminate laser operation.

c. The LRSO is responsible for reporting immediately any case of suspected over-exposure of the eye to laser radiation to the installation surgeon so that an eye examination can be performed within 24 hours of the exposure.

4. Laser Operation. The laser operator will fire only at designated targets which are diffuse reflectors, and will at no time fire at specular surfaces, such as glass, mirrors, windows, etc. This constraint can be met by removing, covering or painting specular surfaces on vehicles.

5. Eye Protection. Those who must be in the target area, such as moving operators or test personnel, shall wear laser protective eyewear with curved protective lenses during laser firing. Such eyewear must be approved for the specific model of laser device being fired. A laser filter designed for protection against one type of laser may not protect against harm from another.

6. Inclement Weather and Night Operations. No precautions other than as previously stated are required at night, or during rain, snow, or fog.

7. Operation Outside of Range Area. The laser system will not be operated or experimented with when removed from its mount unless specifically authorized by the appropriate maintenance manual.

8. Beam Termination. During laser operations no portion of the laser beam will extend beyond the controlled target area. This will be done by construction of the target or choosing a natural target, the size of which will intercept the laser beam and provide an additional buffer zone. Targets will be located in such a manner that they have a geographical backstop, i.e., a mountain or the ground (see Figure 1).

9. Buffer Zone. The extent of the buffer zone depends upon the aiming accuracy of the laser device. The aiming accuracy of the laser device depends upon whether the laser is mounted on a stable platform; i.e., a static base that cannot be easily moved by someone jarring it (e.g., heavy-duty tripod, static tank, reinforced bench mount) or an unstable platform (e.g., light tripod, hand grip, moving tank or aircraft). The static platform generally requires only 2 mil buffer zones; whereas, moving platforms with stabilization generally requires 5 mil buffer zones. For moving platforms without stabilization, 10 mil buffer zones may be required.

10. Optical Instruments. The use of optical devices to observe the target during laser operation will not be permitted unless flat specular surfaces have been removed from the target area or unless appropriate laser safety filters are placed in the optical train of the binocular or telescope.

11. Countdown. A countdown is not required prior to firing in a range environment. The use of range flags during firing serves the purpose of notifying personnel that laser firing or live firing is in progress. Radio communication with personnel downrange in the target area must be provided during laser operation to insure that eye protection is being worn by such personnel.

12. Standing Snow and Water. Hazardous specular reflections from standing snow or water do not present a significant additional hazardous situation to ground personnel and also do not present a hazard to personnel in aircraft outside of the restricted air space above the range.

13. Warning Signs. Evaluation of each anticipated operating condition should include consideration and development of procedures for insuring proper placing of warning signs for that operation. Local standing operating procedures should provide for the placement of temporary or permanent signs during such periods of operation. A sign such as shown in Figure 3 should be used.



Figure 3. Suggested Range Warning Sign